Xe$^+$ FIB Milling and Measurement of Amorphous Silicon Damage

Ron Kelley$^1$, Kai Song$^1$, Brandon Van Leer$^1$, David Wall$^2$, Laurens Kwakman$^2$

$^1$ FEI Company, 5350 NW Dawson Creek Drive, Hillsboro, OR 97124 USA
$^2$ FEI Company, Achtseweg Noord 5, 5651 GG Eindhoven, The Netherlands

Minimizing surface damage during FIB specimen preparation is an important factor for high quality analytical results, especially in the case of TEM membrane and EBSD sample preparation. For conventional Ga$^+$ FIB milling, techniques using reduced accelerating voltages for final polishing to minimize sample damage are commonly used [1]. With newer ion species available for FIB milling, namely Xe$^+$, the ion-solid interaction will be slightly different from Ga$^+$, but the same low ion energy strategies can be applied for minimizing ion milling damage.

Previous studies on single crystal silicon with a conventional Ga$^+$ FIB show ~22 nm amorphous sidewall damage when milled with an energy of 30 keV and less sidewall damage with lower energies. On the same substrate, modeling indicates that milling with heavier ions will produce less sidewall damage than with a lighter ion of the same energy [2]. Hence, less sidewall damage should be achievable when FIB milling with Xe$^+$ (54) in comparison to Ga$^+$ (31). In this study, the sidewall amorphization damage on single crystal silicon after Xe$^+$ FIB milling and also Ga$^+$ FIB milling has been measured for comparison.

Cross-sections of a blanket silicon wafer were prepared using both a Vion™ Plasma FIB (Xe$^+$) and a Helios DualBeam at 30 keV. Specimens were polished with energies of 5, and 2 keV using incident angles of 88°, 86°, 84° respectively. After sputter coating the surface with iridium as an initial protection layer, conventional in-situ liftout TEM samples of the milled cross-sections were prepared using a Helios NanoLab™ 450HP DualBeam equipped with an EasyLift™ nanomanipulator. Amorphous silicon damage was analyzed by HRTEM on a Tecnai Osiris™ TEM operating at 200 keV.

Figs. 1a, 1b and 1c show HRTEM images of the amorphous sidewall damage from Ga$^+$ FIB milling with 30 keV, 5 keV and 2 keV, respectively. Figs. 2a, 2b and 2c show HRTEM images of the amorphous sidewall damage from Xe$^+$ FIB milling with 30 keV, 5 keV and 2 keV, respectively. As expected, the experimental results follow SRIM calculations and predictions from fundamental ion-solid interactions [3]. The Xe$^+$ sidewall amorphous damage decreases dramatically as a function of energy and is smaller than 30 keV Ga$^+$ FIB results by as much as ~40%.

**Figure 1.** HRTEM images of sidewall amorphization damage in Si from a Ga\(^+\) FIB with a) 30 keV, b) 5 keV, and c) 2 keV accelerating voltages.

**Figure 2.** HRTEM images of sidewall amorphization damage in Si from a Xe\(^+\) FIB with a) 30, b) 5, and c) 2 keV.

| Damage Layer Thickness for Xe\(^+\) and Ga\(^+\) FIB Milling (nm) |
|---------------------------------|---|---|---|
| Beam Energy (keV)               | 2 | 5 | 30 |
| Ion Species                     | Ga | Xe | Ga | Xe | Ga | Xe | Ga | Xe |
| ~3 nm                           | ~7 | ~22 | ~3 | ~4 | ~13 | 20 | 35 | 41 |

**Table 1.** Summary table of sidewall amorphization damage layer thickness in Si after Xe\(^+\) and Ga\(^+\) milling with 30, 5 and 2 keV.